49

Preparation of some agriculture derived Biochar using green approach and its application of arsenic removal from water

A

Synopsis

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Table of Contents:

1.1 Introduction: 3
1.2 Overview of Arsenic in India: 4
1.3 Effect of arsenic on Human: 6
2.1 Conventional method of arsenic remediation: 7
2.5 Disadvantages: 8
3.1 Research Gap: 9
4.1 Literature Review: 12
5.1 Characterization techniques: 15
Others techniques 15
References: 16

1.1Introduction:

Arsenic is a metalloid with the atomic number 33 and belongs to group 15 in the Periodic Table. Arsenic can exist in four oxidation states: −3, 0, +3and +5, the later state being the dominant one under oxygenated and normal environmental conditions. The chemistry of arsenic shows similarities with other elements in the same group of the Periodic Table, i.e. nitrogen and phosphorous. **Due to the structural similarity between phosphate (PO_4^{3-}) and arsenate (AsO_4^{3-}) ion, the uptake of arsenic is high (EFSA, 2009). This may also be the reason to explain the high concentration of inorganic arsenic in marine organism and plants.** Ground water contamination of arsenic across the world is an outcome of natural and anthropogenic sources which possess adverse effects on human health and ecosystem. (Bhattacharya *et al.*, 2007) Chronic exposure to inorganic arsenic causes arsenicosis, a disease characterised by the pigmentation of skin, patches on the palm of hand and feet, skin lesions.

Arsenic around the world: Millions of people in several countries are exposed to high levels of As via intake of As-rich groundwater and indirectly via food. High level of arsenic in groundwater of many countries like Chile, Mexico, USA, Hungary, China and Argentina as well as in the India. In the particular, the region surrounded by the state of West Bengal (WB), like Bangladesh and Vietnam (Smedley*et al* .,2002: Bhattacharya *et al.*, 2002) shows severe traces of As. Globally nearly 150 million people around the world are estimated to be affected with an increasing prospect as newly affected areas are continuously discovered. Before 2000, only four Asian countries were arsenic affected namely India, China, West Bengal, and Bangladesh. From 2000-2005 arsenic-related problems were reported in other countries like Nepal, Cambodia, Myanmar, China, Mongolia, Democratic People's Republic Korea and Pakistan. Apart from that some choric arsenic exposure is also reported in Kurdistan province of Western Iran and Vietnam. (Ghosh*et al.*,2009).

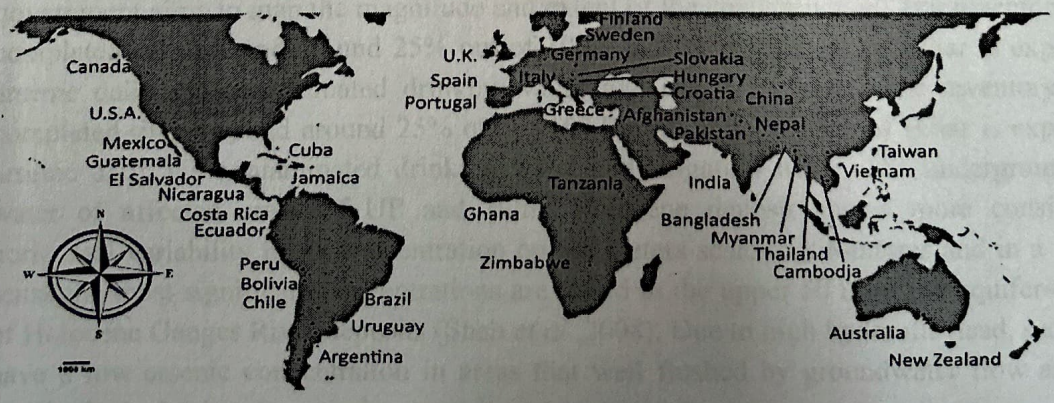


Fig 1: Showing As contamination of drinking water in different parts of world.

(Source: Ahmad, Arslan, *et al.* (2020))

1.2Overview of Arsenic in India:

Presence of As in groundwater in the Ganga-Brahmaputra Fluvial plains of India and Padma-Meghan Fluvial plains in Bangladesh and its impact on human health have been reported as one of the world's most significant natural groundwater calamities to the mankind. Seven states in India namely Uttar Pradesh (UP), Bihar, West Bengal (WB), Jharkhand (in the flood plain of river Ganga), Manipur and Assam (in the flood plain of the Imphal rivers) and Brahmaputra and Rajnandgaon village in Chhattisgarh state have been affected so far by arsenic-contamination in groundwater above the permissible limit of 10 μ g / L. In these states chronic exposure to arsenic were found via drinking arsenic contaminated hand tube wells water Ghosh *et al.*,2009). Day by day, more arsenic affected villages and people suffering from arsenic-related diseases are being reported. Groundwater arsenic contamination and its related consequences include its ingestion via food chain which may be a social disorder, health hazards, socio-economic dissolution besides exploitation of groundwater and its sprawling with movement. Apart from these states many other north eastern hill states in the flood plains are also suspected of having the possibility of ground water arsenic contamination.

Groundwater As first reported in village naming Semria Ojha Patti in Bhojpur district of Bihar state in India, during June 2002. According to a report, three year of intensive research work on in the affected area, 39.02 % of 9,597 samples analysed contained arsenic >10 μg / L and 23 % contained >50 μg / L. Of 4,513 persons screened for arsenical skin lesions, 525 (5.5 %) were registered with skin lesions. In 2002 its area extended further in the Middle Ganges Plain (MGP) of the Ganges Basin, in the states of UP and Bihar, groundwater in Holocene Ganges River deposits is highly As contaminated. The concentration of arsenic in Bihar reaches up to 1800 μg / L, which as far more than the World Health Organization guidelines for safe drinking water of 10 μ g/ L (WHO, 1993). An inventory As campaign by the government aims to map the magnitude and extent of the contamination. The inventory is not completed till now and around 25% out of 103.8 million population of Bihar is exposed to arsenic daily via contaminated drinking water and irrigation water. The inventory is not completed till now, and around 25% out of 103.8 million population of Bihar is exposed to arsenic daily via contaminated drinking water and irrigation water. The underground well water of affected areas of UP and Bihar Holocene deposit shows more considerable horizontal variability in As concentration on ten meters scale to kilometres and in a vertical sense the most significant concentrations are found in the upper 50 m of the aquifer-domain of Holocene Ganges River deposits (Shah *et al.*,2008). Due to high hydraulic head, sediments have a low arsenic concentration in areas that well flushed by groundwater flow and in a poorly flushed subsurface environment its concentration increases.

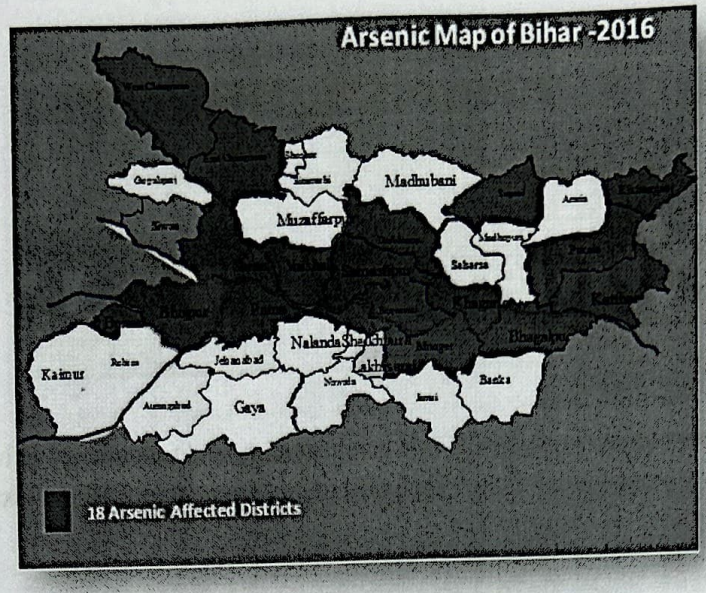


Figure2: Showing arsenic affected districts of Bihar

(Source: Rahman, Md Samiur, *et al.* (2019))

High concentration of arsenic in water was first identified in Semaria Ojhapatti village of Bhojpur district (Chakraborti D *et al.*, 2003). Currently 18 districts in Bihar is reported to have ground water contaminated with arsenic, threating more than 10 million people in the state. (Rahman Md Samiur, *et al.*, 2019) The drinking water source contaminated with arsenic is located in rural habitation sites. A recent report revealed different contaminated level in shallow irrigation bore well water in 36 districts (Bose *et al.*, 2015). The infected sites in Bihar extends westward into the state of UP into Ghazipur, Lakhimpur Kheri, Ballia and Varanasi districts, which covers a more part of the Middle Ganga Plains as well. In 2012 Bihar Ground Water Irrigation Scheme (BIGWIS) was launched to provide irrigation to 9,280,000 hectares of agricultural land of the state. Under this program more than 464,000 tube well which are units of shallow tube well with pump sets installed by 2012 (NABARD Report 2014). From 2014- 2012 more than 36,000 drinking water tube well have been tested, of which 30% have arsenic of more than 50 µg / L (Ghosh *et al.*, 2006). Out of 27000 sample tested in 2005 of the flood plains of Patna, Bhojpur, Vaishali and Bhagalpur districts, 7500 samples had elevated arsenic levels of more than 50 µg / L, the highest being 1861 µg / L in Bhojpur, 608µgL^{-1} in Bhagalpur districts, 150µgL^{-1} in Vaishali and 724µgL−1 in Patna (Ghosh *et al.*, 2006). Till 2014 Bihar especially central region was recognised as a zone of maximum arsenic-contaminated drinking water sources. Inorganic trivalent arsenic has been identified in less than 80% of contaminated irrigation bore well water samples collected from the banks of ganga in Bhagalpur district up to the foothill districts in north Bihar. (Mukherji *et al.*, 2012).

Heavy metal	WHO limit (µg/L)	BIS limit (µg/L)
Arsenic	10	50
Cadmium	3	10
Chromium	50	50
Copper	100	50
Nickel	20	3000
Zinc	3000	5000
Lead	10	100

Table 1: Showing Maximum Contaminant Level (MCL) of some heavy metal WHO: World Health Organization, BIS: Bureau of Indian Standard

(Source: Chennaiah, J. Bala*et al.*, (2014))

1.3 Effect of arsenic on Human:

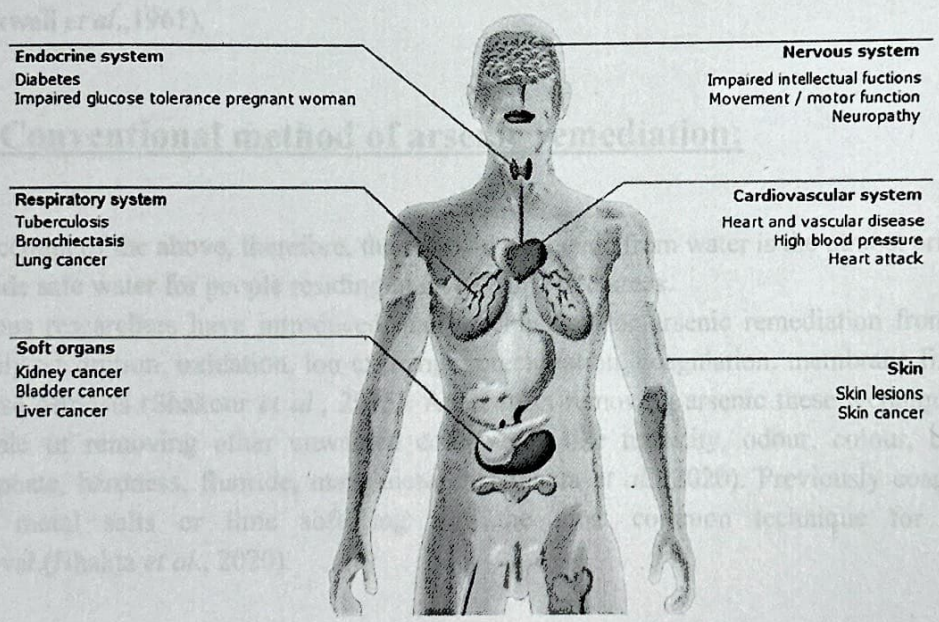


Figure 3: Adverse effect of arsenic due to chronic exposure via drinking water
(Source: Ahmad, Arslan, *et al.*, (2020))

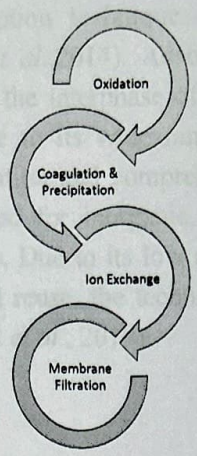
Long term exposure to arsenic can lead to arsenicosis, Blackfoot disease, peripheral vascular disease, skin lesions and cancers as reported in some literature. (Yang *et al.*, 1961). In some reports it is demonstrated that arsenic hinders a series of gene proliferation processes like cell cycle, gene differentiation, repair cycle and DNA damage and damages MAPK pathways, signal transduction, Nrf2-mediated redox signallingpathway (Shanker *et al.*,2014). As also plays a crucial role in triggering o□ cancer via Reactive Oxygen Species formation. In some investigation it is reported that methylated metabolites of arsenic are also potent carcinogens (Eblin *et al.*, 2006). Arsenic is also evident to causes a number of noncancerous multisystemic diseasesincluding dermal disease, hypertension, cardiovascular disease and diabetes mellitus. ROS formation via arsenic is linked with apoptosis, alteration in cell signalling and increase in cytokineproduction, leading to inflammation, which leads to formation of more ROS and mutagenesis, contributing topathogenesis of arsenic-induced diseases. ROS production via arsenic occurs by inducing NADPH oxidase. Elevated level of ROS damage in lipids and protein as well as promoting mitochondrial damage and dysfunction. (Shanker *et al.*,2014).

Chronic ingestion of inorganic arsenic has been known to causes skin abnormalities, such as pigmentation and keratoses. In some studies, it is hypotheses that incidence of arsenic-induced skin lesions and other arsenic-caused diseases might be increased with malnutrition. In Southwestern Taiwan, inhabitants were reported
to have poor nutritional and low socioeconomic status. extremely low in fat (Yang and Blackwell *et al.*,1961).

2.1 Conventional method of arsenic remediation:

On account of the above, therefore, the removal of arsenic from water is the utmost priority to provide safe water for people residing in arsenic affected areas.
Various researchers have introduced many techniques for arsenic remediation from water namely adsorption, oxidation, ion exchange, precipitation, coagulation, membrane filtration, reverse osmosis (Shakoor *et al.*, 2015). Apart from removing arsenic these techniques also capable of removing other unwanted compounds like turbidity, odour, colour, bacteria, phosphate, hardness, fluoride, manganese etc.(Bhakta *et al.*, 2020). Previously coagulation with metal salts or lime softening was the most common technique for arsenic removal.(Bhakta *et al.*, 2020).

Keeping this in mind, it is suggested to remove the As content from the primary source of intake for human beings such as water, food and soil. There are a various method which can be used for As removal. To name few, it can be following



2.2 Oxidation:

This process involves the conversion of soluble arsenite to arsenate with the help of oxidising agent. So, the oxidation alone cannot remove arsenic. Therefore, for complete removal of As, it requires some other techniques. Commonly used chemical agents are hypochlorite, ozone, atmospheric oxygen, hydrogen peroxide, permanganate etc.

2.3 Coagulation and precipitation:

these are the most commonly used conventional technique used in arsenic remediation. In the coagulation process, the coagulating agent was added having a positive charge on them. This positive charge interacts with negatively charge on the colloidal particle and flocculates it. Dissolve arsenic is transformed into insoluble solids by chemical agents and later precipitates. The process produces a large amount of sludge which is a disadvantage.

2.4 Ion exchange:

In this process ions are held on the solid surface via electrostatic force and ion gets exchange from the mobile phase to solid phase. Usually a chlorine loaded ion resin is used for arsenic removal. (Bhakta *et al.*, 2020). The critical factor determining the efficacy of this process are contact time, pH and presence of total dissolved solids.

2.5 Membrane filtration:

these membranes consist of pores which are selective to a particular material like it may not allow some elements in water such as microorganisms, natural organic matter, particulates to pass through. (Bhakta *et al.*, 2019).

2.5 Disadvantages:

Methods mentioned on section 2.1- 2.5 are effective in removing arsenic from contaminated water but are economically not feasible due to high cost, high energy requirement and hazardous sludge generation. Due to its low cost, efficient, adaptable simple operation and

least waste regeneration adsorption technique offer promising alternatives over other conventional techniques (Baig *et al.*,2014). Adsorption is the process of mass transfer in which substance accumulates at the interphase of two phases or target substance separates from fluid to solid surface. Due to its wide range of application and ease of operation, adsorption is considered reclamation and comprehensive techniques for water purification. This process can also be applied for inorganic, organic and biological pollutant with a removal efficiency of up to 99%. Due to its low cost, metal selectivity, higher heavy metal uptake, easy metal recovery and reuse, the technique gained attention for the treatment of industrial waste water. (Merchant *et al.*, 2019).

3.1 Research Gap:

In order to make adsorption process more efficient and removal of arsenic from water, the preparation of new type of highly efficient adsorption material and the use of metal oxide for arsenic adsorption has become a focus of research. (Liu *et al.*,2019). Some research group investigated use of the metal oxide such as iron, manganese and other oxides as well as oxyhydroxides such as magnetite, hematite etc to increase the removal rate of arsenic from water. (Liu *et al.*, 2019). Metal oxide includes alumina (Al_2O_3), iron oxide (Fe_2O_3), Manganese oxide (MnO_2). Many researchers indicate the affinity of iron oxide for arsenite (As III) and arsenate (As V). (Liu *et al.*, 2019). Due to strong oxidising properties, large specific surface area and polymorphic structure, manganese oxide can be used for adsorption. The oxidising property of MnO_2 can convert As (III) to As (V), which is difficult to remove. Disadvantages of using materials are high cost, chemical nature and difficulty in re-use hindered their application.

Therefore, it is necessary to develop an eco-friendly and practical material for arsenic removal from water. The concept of using cheap and readily available materials has grown quickly, which involved the utilisation of solid biowastes (known as 'biosorbent') – the byproducts from food-industry and agricultural wastes. (Shakoor *et al.*, 2019).Naturally biosorbent are algae, fungal biomass, industrial, agricultural biowaste and other biomaterial (including chitosan). These materials offer high surface to volume ratio and have various the functional group at the surface that binds to heavy metal and helps in removal under specific conditions (Anastopolus *et al.*, 2019).

Recently some scientist reported to removing As from surface water by using biomass of blue pine and walnut. Apart from that coconut fibre, dried root of water hyacinth, powdered egg shell, fish scale, human hair, rice husk, bird feather, seed powder of *Moringa oleifera* are also found to be effective in removing arsenic from water by some research group. (Bibi *et al.*, 2017). Due to their abundance in nature, some scientist has investigated the use of agriculture waste or by products for removal of heavy metal. Numerous waste biomass is present in

various parts of the world like rice husk, peanut shell, coir dust, corn cob, saw dust, tea and coffee waste, tree leaves and bark, wheat bran and sea weed etc on which some adsorption properties have been reported. (Cheraghi *et al.*, 2013). Previous research by some scientist has transformed the knowledge of the use of agriculture and food industry solid waste such as pea nut shell, jackfruit peel, sugarcane bagasse, water chest nut shell, rice husk, hazelnut, coconut husk and peels of various fruits as a potential biosorbent for arsenic removal. (Shakoor *et al.*, 2015).

Some research group have examined the potential of mosambi peel, coconut coir pith, orange peel, rice husk, rice polish, rice straw, tea waste under a limited set of aqueous conditions. (Shakoor *et al.*, 2015). Some literature it was found to remove arsenic waste water using scrapes from industries such as red mud, fly ash and waste sludge.Some research groups have also reported the use of carbon-based materials such as carbon nanotubes, graphene and biochar in arsenic removal due to their large specific surface area, high thermal stability and excellent porosities. (Liu *et al.*, 2019). Biochar is the material remain after pyrolysis of carbonaceous biomass from agriculture waste.

Biomass pyrolysis in the absence of oxygen will form solid carbonaceous biochar. (Kumar *et al.*, 2019). High surface area, porosity, surface oxygenated functional group, and presence of inorganic ash are the properties that make biochar a wonderful adsorbent for inorganic and organic contaminants. The presence of a functional group having oxygen will make biochar surface negatively charged. It can be used for removal of anions and oxyanions at low pH where biochar's functional group get protonated. (Kumar *et al.*, 2019).

Biochar may not be much effective as an adsorbent for arsenic removal under alkaline condition. So, to improve adsorption efficiency surface modification of biochar came in to lime light recently. Engineered biochar was found to be effective in arsenite and arsenate adsorption. The property of adsorption in biochar is contributed by function group present on surface of biochar. So, charge on biochar surface is controlled by protonation and deprotonation of the existing surface functional group. At lower pH than the point of zero charge, protonation of some surface group like hydroxyl, carbonyl and ammine will take place, which result in overall positive charges on biochar surface. (Alkurdi *et al.*, 2019). Thus, biochar having acidic pH will favour adsorption of negatively charged pollutant such as arsenate or arsenite and antimonate or antimonites. Some scientist like Zang *et al* used chitosan modified biochar for chromium removal. Liu *et al* used biochar modified with copper (II) and was applied for doxycycline hydrochloride removalfrom water.

So far, a very little work has been done in area of engineered biochar derived from agriculture waste for heavy removal.

Objective: the specific objective of my work is as follows: -

a) Prepare of agriculture derived biochar.

b) Evaluate the As removal ability, sorption mechanism of biosorbent and characterization of biosorbent using modern scientific tools.

c) Determine the effect of pH, contact time, initial arsenic concentration and biosorbent dose on the adsorption of arsenic onto the biosorbent.

Therefore, the aim of my work is to remove arsenic using a green approach and other possible applications.

4.1 Methdology:

Agriculture biomass generated after crop harvesting (like wheat, corn, pulse waste etc)

↓

Pyrolysis in Oven

↓

Pristine biochar

↓

Modification in biochar

↓

Water purification analysis

↓

Standarization of the procedure

4.2 Deliverables:

One of the possible outcomes may be synthesis of engineered biochar having enchanecd surface property and efficency, which is cost effective and simple.

Desining of memebrane filter using engineered biochar as media for water purification.

Other possible applications.

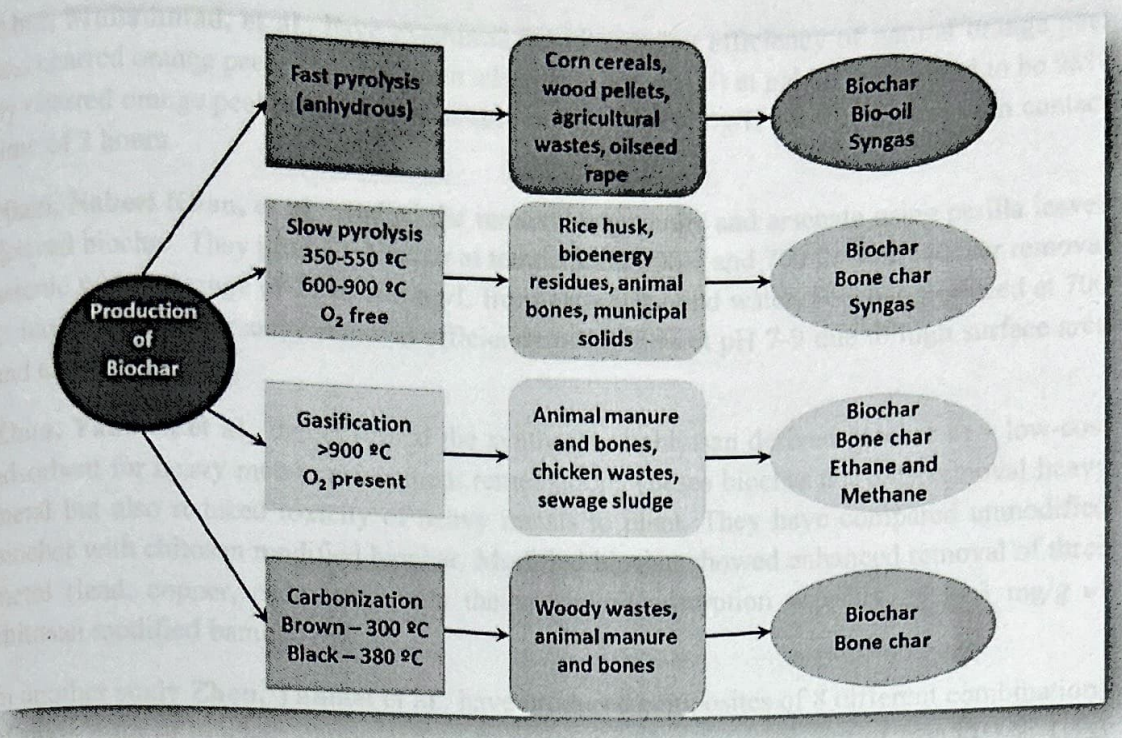

Production of Biochar
Fast pyrolysis (anhydrous)
Slow pyrolysis 350-550 ºC 600-900 ºC O_2 free
Gasification >900 ºC O_2 present
Carbonization Brown – 300 ºC Black – 380 ºC
Corn cereals, wood pellets, agricultural wastes, oilseed rape
Rice husk, bioenergy residues, animal bones, municipal solids
Animal manure and bones, chicken wastes, sewage sludge
Woody wastes, animal manure and bones
Biochar Bio-oil Syngas
Biochar Bone char Syngas
Biochar Bone char Ethane and Methane
Biochar Bone char

Fig4: Showing production of biochar
(Source: Alkurdi, Susan SA, *et al.*, 2019)

4.1 Literature Review:

Shakoor, Muhammad Bilal et al., have explored different types of biosorbents such as water chestnut, java plum seed, corn cob, eggshell, tea waste and pomegranate peel, for arsenic removal from water. At pH 7, eggshell and java plum seed showed maximum arsenite elimination (78-87%) followed by water chestnut shell (75%), corn cob (67%), tea waste (74%) and pomegranate peel (65%). In contrast at pH 4.1 and 5.3 eggshell and java plum seed showed 71 and 67% arsenate removal respectively. After 2-hour contact time the maximum arsenate and arenite absorption was observed in eggshell and java plum seed among all sorbent.

Bibi, Sadia, et al., use potato peel and rice husk for removal of arsenic and fluoride from aqueous environment. The maximum adsorption capacity for arsenic and fluoride was 2.17

µg / g and 2.91 µg /g at pH between 7-9. The potato peel and rice husk ash were also applied to natural ground water with the adsorption efficiency of 90 %.

Abid, Muhammad, et al., have examined the biosorption efficiency of natural orange peel and charred orange peel. The maximum adsorption for As (V) at pH 6.5 was found to be 98% by charred orange peel then 68% by natural orange peel at 4g/L adsorbent dose with contact time of 2 hours.

Niazi, Nabeel Khan, et al., studied the removal of arsenite and arsenate using perilla leaves derived biochar. They produce biochar at temperature 300□ and 700□. Both biochar removal arsenic with the range of 23 to 190 µg/L from natural ground water. Biochar produced at 700 □ have maximum arsenite removal efficiency of 88-90% at pH 7-9 due to high surface area and aromaticity.

Zhou, Yanmei, et al., demonstrated the synthesis of chitosan derived biochar as a low-cost adsorbent for heavy metal environment remediation. Theses biochar not only removal heavy metal but also reduced toxicity of heavy metals to plant. They have compared unmodified biochar with chitosan modified biochar. Modified biochar showed enhanced removal of three metal (lead, copper, cadmium), with the maximum adsorption capacity of 14.3 mg/g of chitosan modified bamboo biochar.

In another study **Zhou, Yanmei et al.**, have produced composites of 8 different combinations of mass ratio of biochar: chitosan: Fe. In samples with greater amount of iron (1:1:2, 1:1:3 and 1:2:3) have high removal efficiency of 70-95% and 91-96% for As (V)and Phosphate. They also have tested removal efficiency of their composite for lead, chromium. 93% removal efficiency was found for lead and for chromium removal efficiency increase with the increasing amount of zero valent iron.

Recently **Zhang, Feng, et al.**, co precipitated magnetite/ water hyacinth composite biochar and was evaluated for arsenate elimination from water. It shows highest sorption capacity (7.41 mg/g) for As (V). Maximum efficiency was achieved in pH range of 3-10 and decreased above pH 10.

In their study of arsenate removal from solution **Duan, Xinhu et al.**, have prepared Fe loaded biochar using walnut shell mixed with $FeCl_3$. It exhibited a sorption capacity of 1.91 mg/g for As (V) and can be easily separated from mixture by applying a strong magnetic field.

In a study by **Nguyen, Nhat-Thien, et al.**, a newly designed composite zinc doped amino functionalization sludge biochar was used for arsenic remediation. At pH 3 the highest adsorption efficiency 79% was observed with 0.84 mg/g adsorption capacity. For the same material the arsenate adsorption efficiency was 98% at pH 3 with an adsorption capacity of 1.43 mg/g.

Sattar, Muhammad Sohail, et al., have examined peanut shell and peanut shell biochar efficiency and was used for arsenite and arsenate removal from water. It was observed that peanut shell biochar possesses higher removal efficiency as comparison to peanut shell with 95% As (III) (at pH 7.2) and 99% As(V) (at pH 6.2) with 0.6 g/L sorbent dose, 5 mg/L initial As concentration, and 2 h equilibrium time.

Luan et al., used intercalation of copper on carbon nanotube membrane for arsenite removal, which leads to more than 90% removal of As (III) in the pH range of 5-9 in the presence of low concentration of nitrate, chloride, bicarbonate and sulfate. Also, the copper/ CNT membrane had high clean water permeability and good reusability as well as efficiency of As(V) removal.

Nguyen, Thi Hanh, et al., investigated the adsorption capacity of fine powdered modified biochar for arsenate removal. The maximum removal efficiency of 63.5% at pH 5 at contact time of 120 mins.

In study by **Kumar et al.**, chromium (VI) removal was investigated using both modified multi walled CNT and pristine MWCNT. At pH 2.5-4, the maximum adsorption capacity for Cr (VI) was found to be 85.83 and 13.2 % for modified and pristine CNT respectively within 40 mins, which is faster than most other carbon-based materials.

Nasir et al., studied, a novel nanocomposite membrane was made using three metal oxides namely iron-nickel-manganese with a ratio of 3:2:1. The maximum adsorption capacity of the membranes observed from Freundlich isotherm model was 41.09 mg/g as obtained by H1.5 membrane at pH 7, with contact time of 12 hours and 100mg/ml arsenic concentration.

Wei et al., synthesizes iron oxide nanoneedles array decorated biochar fiber for arsenic removal from water. The maximum arsenic adsorption was 93.94 and 70.22 mg/g for arsenate and arsenite respectively at pH 7. (18). The biochar supported nanoscale zero valent iron was synthesized and used for arsenate removal from water. At pH 4.1, the maximum adsorption capacity of 124.5 mg/g was observed within a contact time of 48 hrs.

Nashine et al., used coconut fiber for arsenic (lll) removal, having 96% removal efficiency at pH 4 with the adsorbent dose of 10 g/ l and contact time of 8 hrs.

He et al., synthesized cerium loaded cation exchange resin for arsenic removal, with the adsorption capacity of 1.0275 and 2.5297 mg/g for arsenate and arsenite respectively at pH 6 within contact time 6 hours.

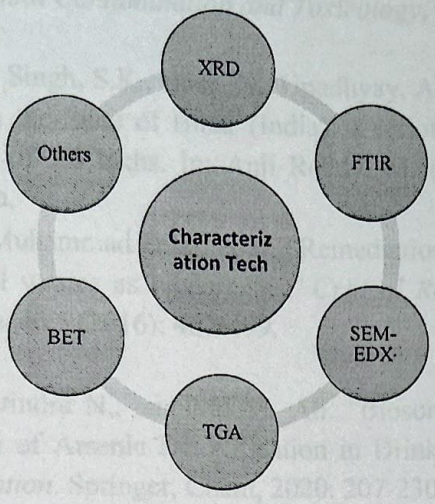
Cheraghi et al., used tea waste as an adsorbent for arsenate removal with removal efficiency of 72 % at pH 6 with contact time of 2 hours was seen.

Dong et al., prepared sugar beet tailoring biochar for chromium (VI) removal. At pH 2, the maximum adsorption capacity of 123 mg /g for Cr (VI) for contact time 16 hours was found.

Lin et al., synthesized Fe/Mn modified biochar for arsenite removal. The maximum adsorption capacity was found to be 8.25 mg/g within the pH rang 3-6 and contact time 24 hours.

He et al., modified fabricated iron impregnated biochar for arsenate removal with the removal efficiency of 6.80 mg /g with contact time of 48 hours.

5.1 Characterization techniques:



X-Ray Diffraction (XRD): it provides detailed information on crystallographic structure and physical properties of material and thin films. The sample is irradiated with a beam of focused monochromatic x rays over variable incident angle range. Interactions with atoms in the sample results in diffracted x rays when brags conditions are satisfied.

Fourier Transform Infrared Spectroscopy (FTIR): it works on the basis of functional groups and provide information in form of peak. It also provides information about chemical composition and can determine range of functional groups.

Scanning Electron Microscopy with Energy Dispersive X Ray Analysis (SEM-EDX): high resolution image of sample is obtained by using a beam of electron rastering across sample surface and secondary electrons or back scattered electrons detected by detector. An EDX analyzer is also used to elemental identification quantitative compositional information.

Thermogravimetric Analysis(TGA): it is the technique to determine weight of a sample with respect to combination of temperature and time. A piece of sample is placed in platinum basket and temperature is continuously recovered by thermocouple under basket.

Brunauer Emmett Teller (BET) Analyzer: this technique is used to measure specific surface area of the particle which includes pore size distribution.

Others techniques

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